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HISTORICAL REVIEW OF ROCKBURSTS IN ONTARIO MINES

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HISTORICAL REVIEW OF ROCKBURSTS IN ONTARIO MINES

by

D.G.F. Hedley*

ABSTRACT

The first reported rockburst in Ontario was in 1928 at a mine in Sudbury. They have continued to the present day. Initially, bursts were mainly confined to the gold mines at Kirkland Lake and the nickel mines in Sudbury, but then spread to the gold mines at Red Lake and the uranium mines at Elliot Lake.

This 60 year period can be divided into three main eras. The first 15 years saw a continuous increase in the number of bursts and fatalities which peaked in 1940. Considerable effort was spent in defining and classifying different types of bursts, developing theories to explain them, altering mining methods and sequence of extraction to reduce the problem, and undertaking geophysical research to determine whether rockburst prediction was feasible.

From 1944 to 1980 no new research initiatives were undertaken. The main effort was in implementing the previously developed rockburst control strategies, with a fair degree of success. Trials continued with different support systems to find those most suitable to withstand the damage associated with rockbursts.

The 1980's have been associated with increased levels of seismic activity in mines across Ontario. An unusual feature has been the multiple nature of the occurrences. Research is being done on the causes and mechanisms of bursts and developing methods to diminish their number, severity, or their damaging effect. Different types of seismic monitoring equipment have been deployed both underground and on surface for accurate source location, determination of magnitude and source mechanism parameters.

This report is a draft chapter of a "Rockburst Handbook for Canadian Hardrock Mines", being produced under the Canada/Ontario/Industry Rockburst Project.

Key words: Rockbursts; Ontario mines; Seismicity.

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HISTORIQUE DES COUPS DE TOIT DANS LES MINES DE L'ONTARIO

par

D.G.F. Hedley*

RÉSUMÉ

Le premier coup de toit signalé en Ontario s'est produit en 1928 dans une mine de Sudbury. D'autres ont suivi et ils continuent à se produire encore maintenant. Au début, les coups de toit avaient lieu surtout dans les mines d'or de Kirkland Lake et dans les mines de nickel de Sudbury, mais ils se sont ensuite étendus aux mines d'or de Red Lake et aux mines d'uranium d'Elliot Lake.

Cet intervalle de soixante ans peut être divisé en trois périodes principales. Les quinze premières années ont été marquées par une augmentation continue du nombre de coups de toit et d'accidents mortels qui a atteint un maximum en 1940. Des efforts considérables ont été consacrés à la définition et à la classification des différents types de coups de toit, à l'élaboration de théories pour les expliquer, à la modification des méthodes d'exploitation minière et de la séquence d'extraction en vue de réduire le problème et à la réalisation de recherches en géophysique dans le but de déterminer s'il était possible de prévoir les coups de toit.

De 1944 à 1980, aucune nouvelle recherche n'a été entreprise. Durant cette période, on a surtout cherché à appliquer, avec un certain succès, les stratégies antérieurement mises au point contre les coups de toit. On a poursuivi les essais avec différents systèmes de soutènement pour trouver ceux qui étaient les plus appropriés pour résister aux dommages dus aux coups de toit.

Au cours des années 1980, le niveau d'activité sismique s'est accru dans les mines partout en Ontario. Pendant cette période, les épisodes ont été caractérisés par une fréquence élevée inhabituelle. On fait actuellement des recherches sur les causes et les mécanismes des coups de toit, et l'on tente de mettre au point des méthodes pour en réduire le nombre, la gravité et les conséquences. Différents types d'appareils de surveillance sismique ont été mis en place à la fois dans le sous-sol et à la surface pour localiser avec précision les sources et déterminer la magnitude des secousses et les paramètres des mécanismes source.

Le présent rapport constitue une ébauche d'un chapitre du manuel "Rockburst Handbook for Canadian Hardrock Mines" produit dans le cadre du projet Canada/Ontario sur les coups de toit.

Mots clés : Coups de toit; mines de l'Ontario; sismicité

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INTRODUCTION

Rockbursts are a 20th century phenomena. They first occurred at the turn of the century in the gold mines on the Witwatersrand in South Africa and on the Kolar Gold Field in India. A South African Commission in 1908 first established that the tremors being felt on surface were mining induced, rather than from natural forces (i.e., earthquakes). The term 'rockburst' apparently was used to describe the 'shattering of support pillars' observed underground.

In Ontario, rockbursts first became a problem in the mid-1930's in the gold mines at Kirkland Lake and in some of the nickel mines in Sudbury. Subsequently, other mining camps experienced bursts, gold mines at Red Lake and Larder Lake in the 1960's, and the Elliot Lake uranium mines in the 1980's. Gold mines in the Timmins area are of a similar age, depth and geometry as those at Kirkland Lake, but only the occasional, isolated rockburst has been reported.

Mines in other provinces of Canada have also experienced rockbursts but to a lesser extent than those in Ontario. So called mining induced earthquakes have occurred above the potash mines in Saskatchewan. Rockbursts have been reported at some of the gold mines in the Val d'Or area of Quebec. The lead-zinc mines in New Brunswick have experienced rockbursts. In 1958 a rockburst (called a bump) at the Springhill Colliery in Nova Scotia resulted in 75 fatalities. Finally, in Newfoundland a fluorspar mine experienced rockbursts at a depth of only 150 m.

ROCKBURST TERMINOLOGY

Over the years a considerable effort has been spent on finding an adequate definition, classification system and reporting procedure for rockbursts.

In the 1939 Ontario Mining Act, a rockburst was defined as:

"a phenomenon causing a fall of ground into an excavated area, or a movement of ground in or about an excavated area and characterized/accompanied by a shock or tremor in the surrounding rock".

The 1978 Occupational Health and Safety Act for Ontario mines modified the definition to:

"an instantaneous failure of rock causing an expulsion of material at the surface of an opening or a seismic disturbance to a surface or underground mine".

There have been numerous other proposed definitions, generally referring to a sudden release of energy or stress. They all suffer from the same ambiguity in that the term 'rockburst' is used to describe the damage or failure process as well as the sounds and vibrations emanating from the source. In some cases vibrations are felt but no damage can be found.

Over the past two decades, microseismic systems installed underground have indicated that the seismic events which cause damage are only a very small proportion of the total number recorded. This led to the concept, initially in South Africa, of first defining a seismic event, then a rockburst as a sub-set of seismic events, which eliminated the ambiguity in the above definitions.

Based on the definitions used by the Chamber of Mines of South Africa (1982), the following definitions are used throughout the report.

A Seismic Event is a transient earth motion caused by a sudden release of potential or stored strain energy in the rock. As a result, seismic energy is radiated in the form of strain waves. The magnitude of a seismic event is usually determined from the peak amplitude of the strain wave, using a logarithmic scale (e.g., Richter Scale).

A Rockburst is a seismic event which causes injury to persons, or damage to underground workings. The general and essential feature of rockbursts is their sudden, violent nature.

Consequently, all rockbursts are seismic events, but not all seismic events are rockbursts.

Initially, both the Kirkland Lake and Sudbury mines used a similar classification system for rockbursts. Strain bursts were caused by high stress concentrations at the edge of mine openings. Events range from small slivers of rock being ejected to collapse of a complete wall. These small bursts were normally associated with development drifts including shafts.

Pillar bursts were the sudden failure of complete pillars when they became too small and overloaded. These tended to occur in extensively mined-out areas and the damage was significant. Multiple pillar failures were usually called Crush bursts and, although few in number, they caused the most serious problems.

Subsequently, the Sudbury mines changed their classification systems. Inherent bursts replaced strain bursts to emphasize that the pre-mining stresses were high enough to cause failure when the initial development openings were driven. Induced bursts replaced pillar and crush bursts. These were caused by mining operations transferring and concentrating stress on the remaining structures such as pillars.

In the 1980's the classification of strain and pillar bursts has been retained, and a third type has been added. When slippage suddenly occurs along a geological weakness plane a Fault-slip burst is produced. This is the same mechanism as for an earthquake. Previously, a number of large seismic events were reported as unlocated. It is probable that these were fault-slip events.

From 1928 to 1988 almost 4,000 rockbursts, and 56 associated fatalities

have been reported to the Ontario Ministry of Labour or its predecessor, the Department of Mines, as shown in Figure 1. As can be seen, by the end of the 1930's, rockburst incidents and fatalities were increasing at an alarming rate. As described later, this led to an extensive research effort within the mining industry, to develop methods to alleviate the problem. These methods were partially successful and the frequency of bursting declined during the 1940's. In the 1970's and 80's the reported level of rockburst activity has been relatively low.

During this 60 year period the criteria for reporting rockbursts have been changed several times. Prior to 1939, there was no formal requirement to report rockbursts other than those causing injury to persons. However, the Ontario Mining Association had developed their own reporting procedure which included: "noticeable damage to timber or other supports, or resulted in appreciable delays to operations". A modified form of this procedure was incorporated into the 1939 Ontario Mining Act, where it was necessary to report a rockburst if it was determined that it had occurred within the mine workings.

In the 1978 Act the damage criteria were changed to: "where a rockburst occurs causing damage to equipment or the displacement of more than five tonnes of material".

Both the 1939 and 1978 Acts require a visual confirmation of damage. Consequently, seismic events that occur in abandoned areas of a mine, with no access for visual confirmation, are not reported. Similarly, fault-slip seismic events, out in the wall rocks, which produce no damage are not reported. As described later, during the 1980's, a significant number of large seismic events either occurred in abandoned areas of mines or out in the wall rocks. These events are not included in Figure 1.

Since 1984, all large seismic events in Ontario mines are classified by

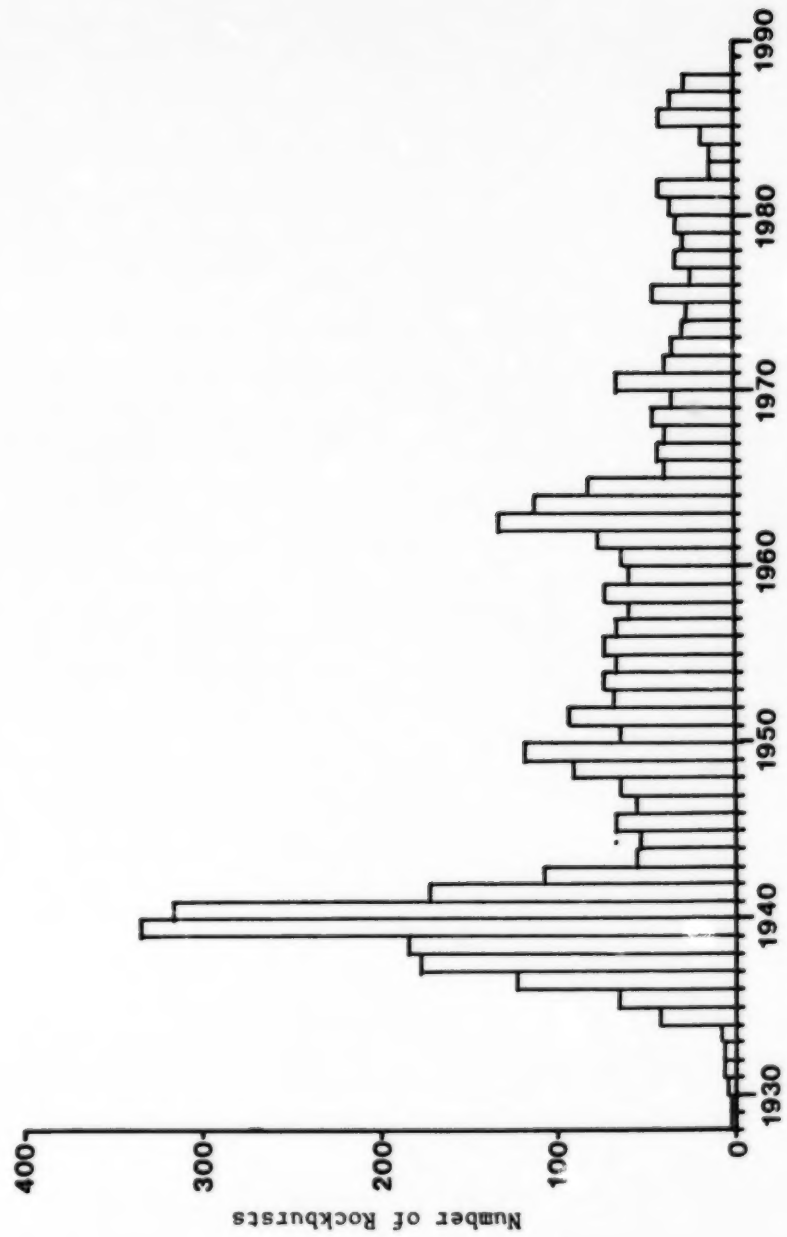
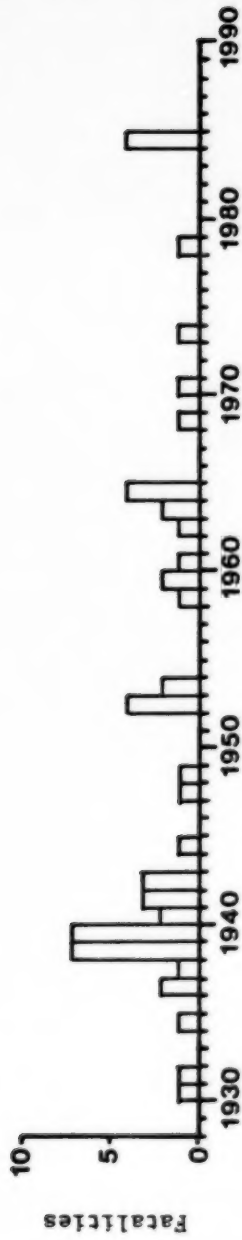


Fig. 1 - Reported rockbursts and fatalities in Ontario mines, 1928-1987.

magnitude, with a lower threshold of 2.0. These events are recorded on the Eastern Canada Seismic Network, operated by the Geophysics Division of the Geological Survey of Canada, who calculate the magnitude values.

INITIAL ROCKBURST INVESTIGATIONS

The first reported rockburst in Ontario was in January, 1928, at a depth of 670 m in the Mond Shaft of the Frood Mine in Sudbury. By the mid-1930's significant rockburst activity was occurring in the Lake Shore, Teck-Hughes and Wright-Hargreaves mines in Kirkland Lake. In the Sudbury area both Frood and Creighton mines were experiencing bursts. Over the next ten years extensive observations, modifications to mining methods and research were undertaken to alleviate the rockburst problems at these mines, with some measure of success. The Kirkland Lake mines published numerous papers on rockbursts during this period, with the Lake Shore Mine taking the lead. Unfortunately, there was no published material on the Sudbury mines.

KIRKLAND LAKE MINES

At Kirkland Lake the gold-bearing quartz veins are associated with several fault systems designated as the 'Main Break' or Kirkland Lake Fault. This fault extends across the whole mining camp in an East-West direction and dips steeply to the South. From East to West the mines were: Toburn, Sylvanite, Wright-Hargreaves, Lake Shore, Teck-Hughes, Kirkland Lake Gold and Macassa, of which only the latter is still in production. Mining has progressed down to a depth in excess of 2000 m. Shrinkage methods were used at shallow depth, and then generally converted to cut-and-fill methods using waste rock, sand and gravel as backfill. At most mines several sub-parallel veins are present, typically 2 m wide. The host rocks are porphyry, tuff and basic syenite, all of which are hard and brittle.

With the increasing number of rockburst incidents the Kirkland Lake

Mine Operators' Rockburst Research Committee was formed in 1939. One of the first acts of this committee was the preparation of three papers dealing with the rockburst problems at Teck-Hughes (Christian, 1939), Wright-Hargreaves (Robertson, 1939), and Lake Shore (Robson et al., 1940). These papers give a good indication of the state-of-the-art of rockburst occurrences and control methods employed at that time.

Bursting first occurred at the Lake Shore Mine in a floor-pillar (i.e., crown pillar) on the 1200 level (370 m). By 1934, bursting had assumed noteworthy proportions, usually in the horizontal floor pillars of shrinkage stopes. Below the 1600 level (490 m), stoping was converted to horizontal cut-and-fill. This alleviated the rockburst problem until the 2200, 2325 and 2450 level stopes had advanced to within 12 m of the level above, when bursting resumed. To avoid the formation of floor pillars, a steep square-set rill system of stoping with close backfilling was adopted below the 2700 level (820 m). Figure 2 shows a longitudinal view and cross-section of the east side of the mine. Middle and South veins, up to 20 m apart, were being mined concurrently. The locations of the rockbursts that occurred between 1936 and 1939 are also shown in Figure 2. They were mostly associated with mining of the South vein where the host rock was hard brittle porphyry with an extremely complex system of jointing.

Figure 3 is a longitudinal section of the Teck-Hughes Mine. Shrinkage stoping was used down to a depth of 1870 m. In most cases the empty stopes were allowed to slough. Waste rock backfill was only used in stopes adjacent to shafts and major haulage ways to prevent sloughing. Rockbursts at Teck-Hughes were concentrated around the west end of the 38 level and the central portion of the 45 level. These areas were associated with a very brittle tuff and a highly siliceous porphyry zone, respectively.

The factors affecting the incidents and severity of rockbursts, at

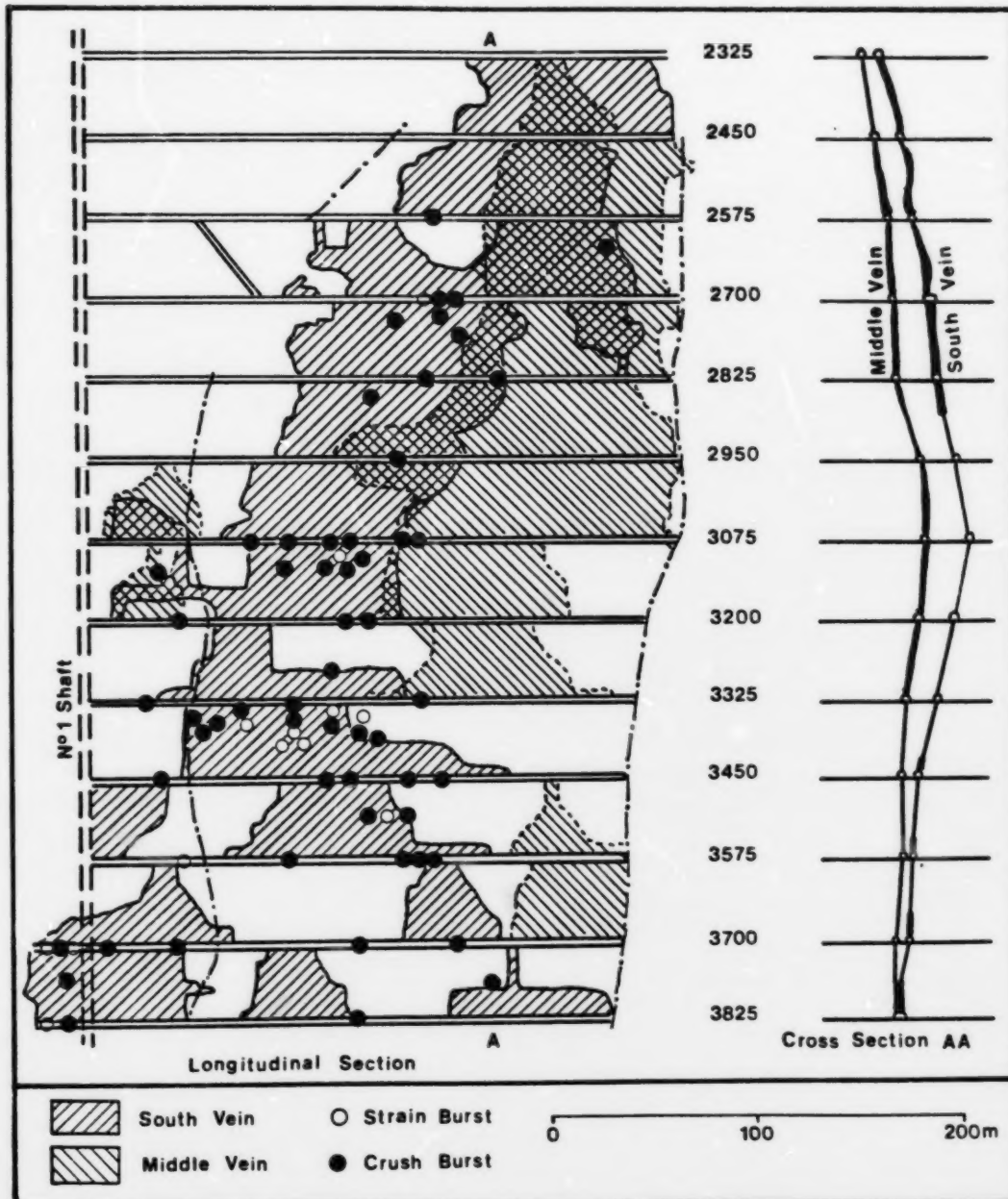


Fig. 2 - Mining layout at the Lake Shore Mine showing locations of rockbursts (after Robson, 1940).

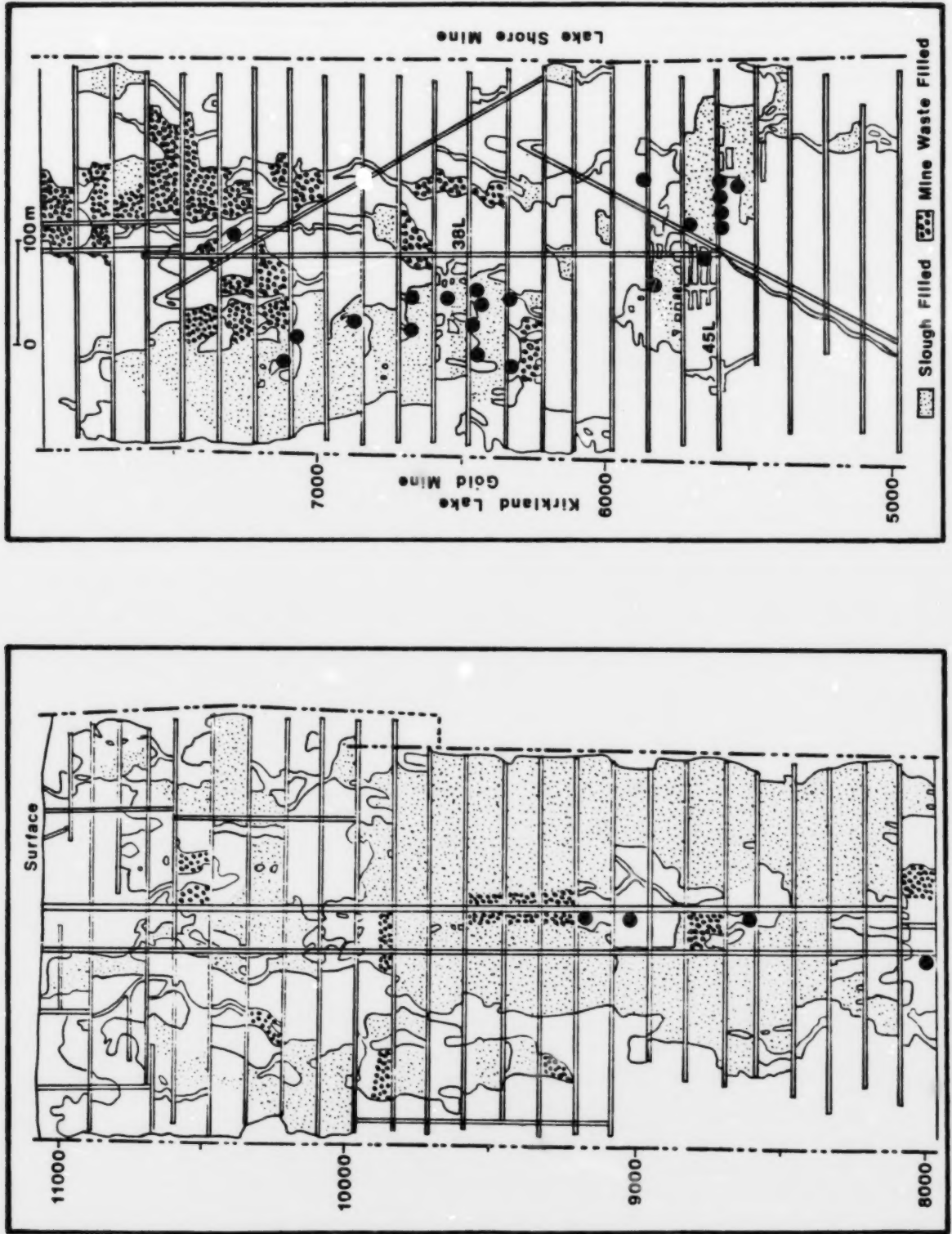


Fig. 3 - Mining layout at the Tech-Hughes Mine showing locations of rockbursts (after Christian, 1939).

these mines, were reviewed.

a) Depth of Workings

The number and violence of rockbursts increases with depth. This was explained in terms of a 'doming' theory. Stopping results in an arched area of disturbed and fractured rock in the hanging wall, and to a lesser extent, in the footwall. The size of the dome is controlled by the span of the excavation, properties of the wall rocks, method of support and depth. Rockbursts were attributed to the formation of these domes, and the more severe bursts to the merging of domes.

b) Structural Features

Hard brittle rocks are more susceptible to bursting than softer, weaker rocks. Joints, faults and dykes are lines of weakness and play some part in the incidence of rockbursts.

c) Dip of Orebody

Rockbursts are more apt to occur in steeply-dipping deposits than in those that are gently-dipping. The reason for this was vague, being ascribed to the cumulative build-up of tangential stress in the wall rocks with depth.

d) Sequence of Stopping Operations

Scattered stopping operations result in the formation and merging of many domes. Sequencing should be designed to prevent the formation of remnant or promontory pillars and the sudden extension of domes from one area to another.

e) Rate of Mining

Settlement of ground goes on regardless of the rate of stopping, resulting in steadily increasing pressure. Under these conditions, stopping should be as rapid as possible.

From these and other observations the following guidelines were drawn.

- a) Many rockbursts occur at the time of a blast, or shortly afterwards, which

led to the introduction of central blasting off-shift.

- b) Leaving small remnant pillars, of ore or waste, should be avoided to allow gradual and uniform subsidence of the hanging wall.
- c) Thin horizontal pillars were rockburst-prone and must be avoided, or mined as soon as possible.
- d) Vertical pillars, such as around shafts and the property boundary were generally stable.
- e) Mining out remnants from two directions was not good practice.
- f) Steep rills avoid the formation of horizontal remnants and were less susceptible to bursts.
- g) Long rills, extending from level to level, and advanced towards unmined ground were less susceptible to bursts than those mining towards each other.

The use of backfill to control the number and severity of rockbursts was not followed by all. Both Lake Shore and Wright-Hargreaves used tight backfill, and the former even filled all the old shrinkage stopes. Teck-Hughes used shrinkage methods exclusively and considered the use of backfill as an economic matter unrelated to the control of rockbursts.

Many of the observations and guidelines presented in these reports are still relevant. However, some concepts have changed. Rockbursts in steeply-dipping orebodies are the result of high horizontal stresses, which are greater than the vertical gravitational stress. This was discovered in the 1960's when stress measurements were taken in a number of Ontario mines. The concept of 'doming' to explain rockbursts has been replaced by an energy balance approach. Domes, or expansion zones, do exist in the stope walls and small tensile stresses are present. However, the extent of these expansion domes decreases with increasing depth (Salamon, 1974). What was not recognized, is that when a pillar fails there is a sudden convergence of the

wall rocks with a change in potential energy. This is the source of the energy liberated in a rockburst. Although faults, joint sets and dykes were considered to have an important effect on rockburst incidents, the concept that slippage on these structures could be the cause and source of rockbursts was not recognized. This, despite the fact that some of the large tremors were reported to have occurred deep-seated in the wall rocks, which could only have occurred with a fault-slip mechanism.

MORRISON'S REPORT

It appears that the Kirkland Lake Rockburst Committee was superseded, in 1940, by a Rockburst Committee of the Ontario Mining Association. This latter committee retained R.G.K. Morrison, Superintendent, Nundydroog Mines on the Kolar Gold Field to investigate rockbursts in Ontario mines. Three months were spent visiting mining camps throughout Ontario (Kirkland Lake, Larder Lake, Porcupine, Sudbury, Little Long Lac, Pickle Lake, Uchi Lake and Red Lake). A report on the rockburst situation in Ontario mines was published in the Transactions of the Canadian Institute of Mining and Metallurgy in 1942. In many respects this report formed the basis for implementing rockburst-control strategies at Ontario mines for the next 40 years.

Rockbursts were attributed to the formation of 'domes', which was the prevalent theory being used on the Kolar Gold Field, the Witwatersrand, and at Kirkland Lake. Figure 4 illustrates this doming concept. Individual stopes are surrounded by a dome of fractured rock. As stopes approach each other the intervening pillars become increasingly stressed. If these pillars suddenly fail, the volume of the dome also suddenly increases (i.e., approximately quadruples for the merging of two equally sized stopes). The rupture of the large volume of rock between two or more initial domes, and the release of its accumulated energy results in a rockburst. The magnitude of the rockburst depends on the final size of the dome and the energy stored within it. This,

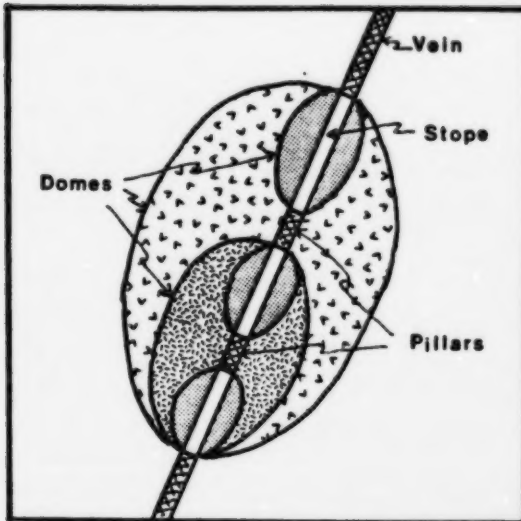


Fig. 4 - Concept of doming theory (after Morrison, 1942).

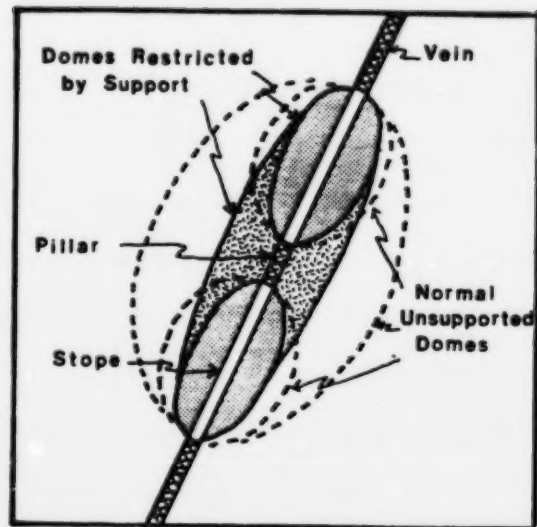


Fig. 5 - Effect of support on the size of domes (after Morrison 1942).

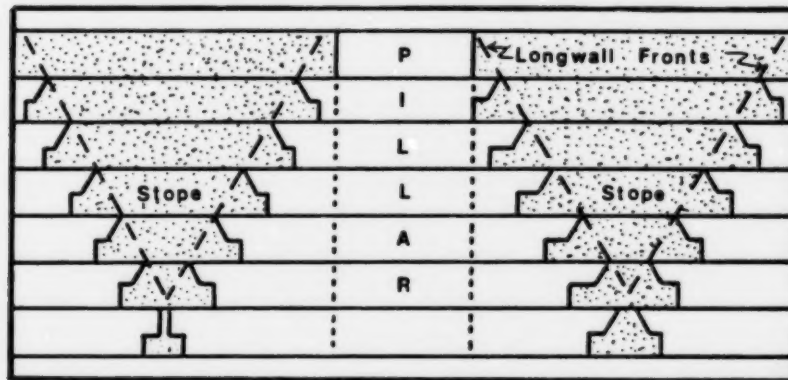


Fig. 6 - Longitudinal cut-and-fill layout with longwall configuration (after Morrison, 1942).

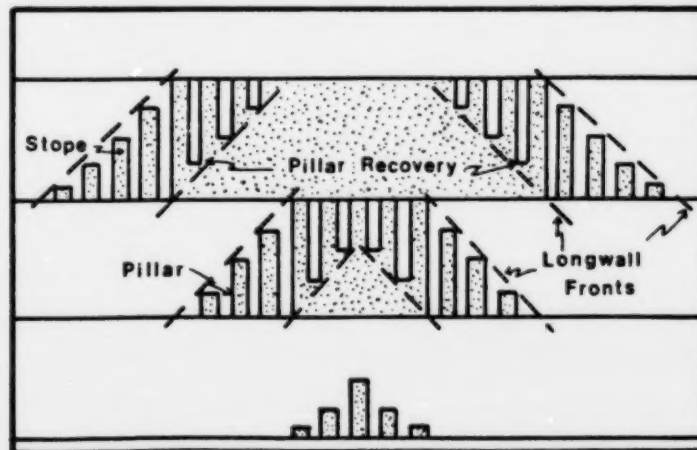


Fig 7 - Transverse cut-and-fill layout with longwall configuration in primary stoping and pillar recovery (after Morrison, 1942).

in turn, is controlled by the areal extent of stoping, depth, and the physical properties of the wall rocks.

Although the formation of domes as a rockburst mechanism has been discredited, many of the characteristics associated with domes are still relevant to rockburst-control strategies. Areal extent of stoping, depth and elastic properties of the wall rocks also control convergence and change in potential energy of the surrounding rock mass. When a pillar fails between two equally sized stopes, the change in potential energy quadruples, similar to the volume of a dome.

The importance of support for controlling the number and severity of rockbursts was recognized, although again in terms of its effect on the size of domes, as illustrated in Figure 5. It was also recognized that some type of cushion was required. Although not implicitly stated, this was so the support could withstand the impact loading resulting from a rockburst.

Morrison's main rockburst-control strategy was the use of mining layouts which eliminated small remnant pillars and allowed domes to gradually expand. In practice, this meant some form of longwall configuration. Figures 6 and 7 show two possible longwall stoping layouts for longitudinal and transverse cut-and-fill mining.

The effect of weakness planes such as faults, dykes, contacts, and major joint sets, was explained in terms of their effect on the formation of domes, and stress concentrations. The concept of slippage along these structures was not recognized. It was recommended to mine away from major weakness planes, or to mine through them at a perpendicular rather than an acute angle.

Many of the recommendations in Morrison's report were implemented by the Ontario mines and the number of rockbursts did substantially reduce in the 1940's, as shown in Figure 1.

GEOPHYSICAL RESEARCH

During the 1930's, some of the larger rockbursts at Kirkland Lake were recorded 450 km away on the seismograph of the Dominion Observatory in Ottawa. This led to a proposal by Lake Shore Mines Ltd., in 1938, that a seismograph station be established at Kirkland Lake, and that geophysical research on rockbursts be undertaken at the mine. Direction of this research was assigned to Dr. E.A. Hodgson, Chief of the Seismological Division of the Dominion Observatory. The main objective of the geophysical research was to determine whether rockburst prediction was feasible. However, these rockbursts were also used as a convenient source for refraction profiles and crustal velocity models of the Canadian Shield. A detailed report on the rockburst research, between 1938 and 1945, was published by the Dominion Observatory in 1958.

A parallel research effort was also being done at INCO's Frood Mine at Sudbury. On a number of occasions the two research teams collaborated on the testing of new monitoring equipment.

The surface seismograph unit at Kirkland Lake was installed in December 1939, and was in almost continuous operation until the late 1950's. A number of devices were tested underground to monitor increasing stress. These included instrumentation to measure borehole and drift closure. Although some results were obtained, the instrumentation was cumbersome. Similarly, measuring an increase in temperature with increasing stress was not feasible, neither was measuring seismic velocity, since time could not be measured accurately enough.

A considerable effort was made to measure the frequency spectra of seismic events, blasting and other mining noises. Filters were made to try to eliminate non-seismic noises, without noticeable success. Other factors also affected or delayed the instrumentation program. In a wartime economy, electronic components were scarce, and much of the equipment had to be custom

built. The Lake Shore Mine operated on 25 cycle power supply, with a fairly severe voltage fluctuation, whereas the electronic equipment was designed for a 60 cycle supply. Most of the electronic equipment was not designed to operate in a hot, dusty and damp underground environment.

In June 1942, Dr. L. Obert from the United States Bureau of Mines visited both Frood and Lake Shore Mines to demonstrate a microseismic monitoring system. Sub-audible noises up to 1000 Hz were recorded either using ear-phones or on a paper chart. Research in a Michigan mine had indicated that microseismic activity, as expressed in events per minute, increased before a rockburst. The demonstration tests at Frood and Lake Shore mines indicated that microseismic events could be readily detected with this equipment.

A comprehensive monitoring program was initiated in July 1942 at the Lake Shore Mine. Three of Obert's recording units were purchased and up to 100 geophones were installed underground to monitor microseismic activity. This program lasted for approximately three years.

Since the background noise at the mine was so high, microseismic monitoring was eventually limited to off-shift periods. Monitoring at each site would be done over a 15 minute period using either ear-phones or a paper chart recorder. It was found that seismic events detection was limited to within 20 m of a geophone.

Initial tests indicated that an event rate of less than 20/min was no cause for concern. Over 20 events/min required close inspection of the affected stopes, and over 80 events/min meant withdrawing the labour force from the stope and, if possible, the next blast should be made abnormally heavy. Other observations were that various parts of a pillar would have higher event rates at different times, indicative of shifting stresses which could occur fairly rapidly. Also an increasing event rate would often be

followed by a quiet period, just prior to a rockburst.

A particularly heavy rockburst on 29 January 1943, destroyed all the geophones and cable in the test area, as well as blocking off four levels (3825 to 4200 as shown in Figure 8). The event rate records on two geophones, leading up to this major rockburst, are shown in Figure 9. The event rates were erratic, alternating between background noise of 20 events/min and peaks of over 100 events/min. Unfortunately, the paper chart records for the day prior to the rockburst were destroyed by the burst.

Subsequently, this area of the mine was closed down for the duration of the war. The microseismic equipment was moved to another part of the mine, which happened to have a relatively low level of seismicity. During the next one-and-a-half years only three rockbursts occurred near the instrumented site, other than at times directly after blasting. There was no clear indication of an increasing event rate prior to these rockbursts. In October 1945, the research program was terminated by the company. Some six weeks later a large rockburst occurred in the area which had been covered by the equipment.

In many respects the monitoring program at Lake Shore Mine was the fore-runner of the present day microseismic systems. With electronics and computing devices being in their infancy it lacked the continuous recording ability, rapid evaluation of data and inter-connected, multi-channel aspects of the present systems. It appears from the reports that the research program became saturated with data. The schedule was that the seismologist went underground at 3 am each day and collected the paper chart records, as well as listening with earphones on selected geophones. At 7 am the records were brought to surface and the event records on the charts (about 12 m long for each recording) were manually counted. Event rates for the various locations were then given to the company officials for the morning shift. About six

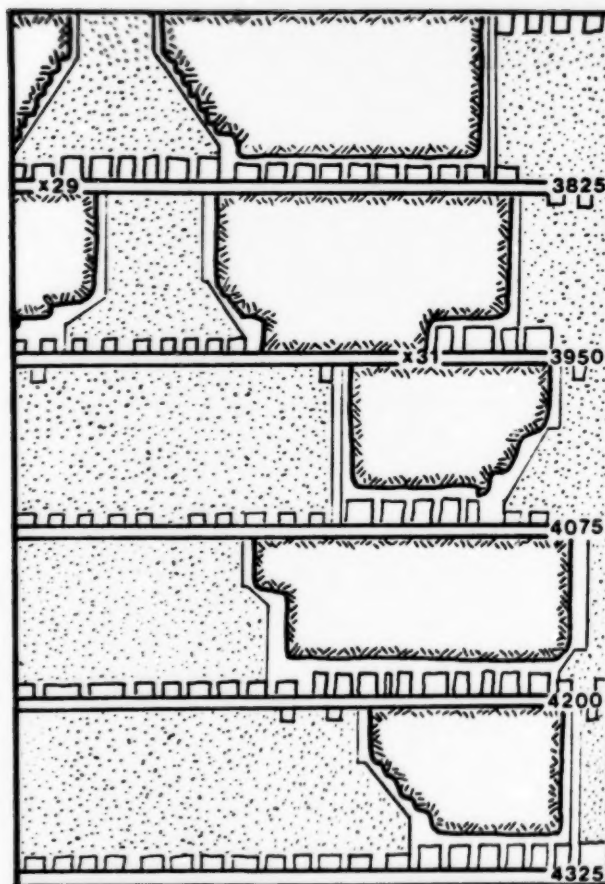


Fig. 8 - Mining layout at the Lake Shore Mine at the time of a major rockburst (after Hodgson, 1958).

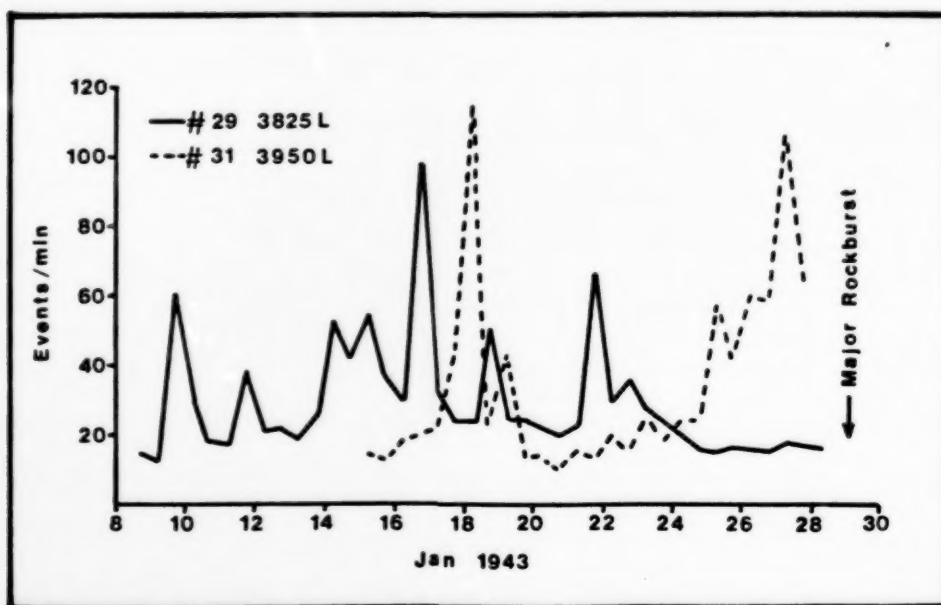


Fig. 9 - Seismic event count rate prior to a major rockburst (after Hodgson, 1958).

persons were required to keep the instrumentation in operation. collect the data and analyze the results. Inevitably this level of activity could not be sustained. and with low seismicity activity in the area. the program was cancelled.

The prime objective of rockburst prediction. in the time domain. was never achieved (and still has not been achieved some 40 years later). A more modest objective of identifying rockburst-prone areas of the mine and its relation to geological structure and mining activity may have been more attainable. However. the research team had no mining experience. and liaison with mining personnel concerning mining activity was sporadic.

IMPLEMENTATION OF ROCKBURST CONTROL STRATEGIES

During the 1950's. 60's and 70's. very little basic rockburst research was undertaken in Ontario. The main emphasis was on implementing and modifying the rockburst control strategies developed during the 1940's. This included adoption of longwall mining layouts. avoidance of remnant pillars and conversion of shrinkage to cut-and-fill at depth. The introduction of cemented backfill and rock bolts also assisted. It should be noted that by the mid-1960's all the gold mines at Kirkland Lake. except the Macassa Mine. had closed. which significantly reduced the rockburst frequency in the province.

During this 30 year period a few papers were published on rockbursts in Ontario mines. The most significant of these were on the control strategies developed at the Creighton Mine (Dickhout. 1957. 1962). and at the Lake Shore Mine (Robson et al.. 1957). Also an account was written on the large rockburst sequence that closed the Wright-Hargreaves Mine (Buckle. 1964).

CONTROL MEASURES AT CREIGHTON MINE

Creighton Mine first experienced rockbursts in the mid-1930's when

mining below 600 m. The general pattern was for 'inherent' bursts to occur during development. These were caused by the high, pre-mining field stresses, and the brittle nature of the rock. After about 60 to 70% of a level had been mined, 'induced' bursts would occur in crown pillars. This was followed by 'induced' bursts in development openings in the wall rocks, and finally by unlocated bursts in the wall rocks.

The control methods adopted were based on the doming theory. Major development openings such as shafts were sunk in the footwall well outside any subsequent dome produced by mining. No. 6 internal shaft, sunk to a depth of 1700 m, experienced major 'inherent' bursting problems in the walls and at the bottom. This shaft was converted from rectangular to a semi-elliptical shaft and blasting was reduced to 2 m lifts, as well as forming a concave shaped bottom. The concrete lining was also kept within 1.5 m of the shaft bottom. These measures decreased the severity of the rockbursts.

At depth, destressing techniques were used in driving development drifts as illustrated in Figure 10. Two boreholes would be drilled 7.5 m and 15 m ahead of the face, but only the longer hole would be loaded and blasted. This resulted in a large decrease in overbreak, working ground and spalling. Main shaft crosscuts and haulage drifts were supported with lagged steel sets, either a horizontal cap with vertical posts or an A-frame cap with vertical posts.

Below a depth of about 1200 m square-set stoping was used exclusively with water-borne sand filling. The standard layout was 5-set stopes (9.3 m wide) and 4-set pillars (5.8 m wide). The mining sequence is shown in Figure 11. Both primary stoping and pillar recovery were advanced upwards on a longwall front. Only one level was allowed to merge with the one above at any one time, so that the domes increased gradually. When the lead stope approached the level above some bursting was experienced, but multiple and

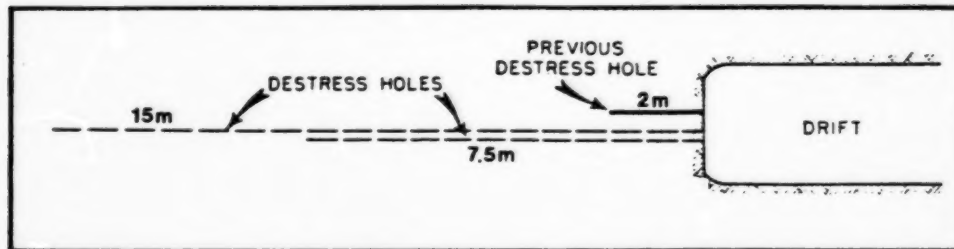


Fig. 10 - Layout of destress boreholes ahead of a drift (after Dickhout, 1962).

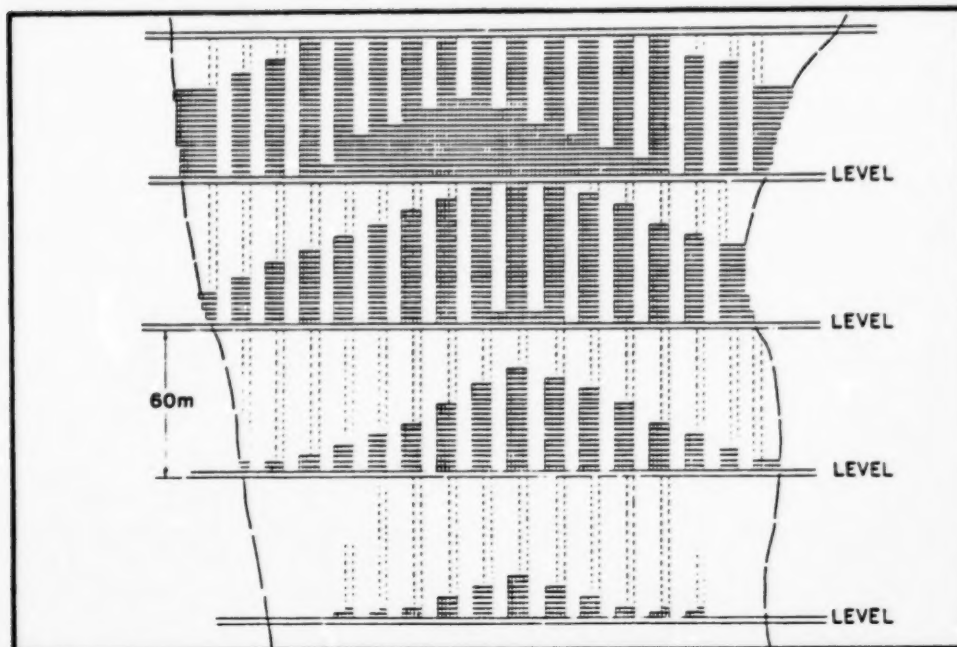


Fig. 11 - Mining sequence with square-set stoping and backfill (after Dickhout, 1962).

severe crown bursts were eliminated. Subsequently, the introduction of cemented backfill eliminated the square-sets, however, the sequence of mining was still retained.

CONTROL MEASURES AT LAKE SHORE MINE

Mining methods were changed with increasing depth (down to 2450 m) and a severe rockburst problem at the Lake Shore Mine. Shrinkage stoping at shallow depth was replaced by flat-back cut-and-fill and all the old excavations were backfilled with sand. The thin sill pillars of these cut-and-fill stopes began to burst at moderate depth. The next modification was to mine the lower half of a stope with flat-back and cut-and-fill, then the upper half with rill stoping. Eventually, with increasing depth, these larger sill pillars began to burst. This led to complete rill stoping between levels with square-sets and backfilling with sand and waste rock.

The sequence of mining was rigorously controlled so that stopes were kept in alignment with no pillars projecting into mined-out areas. Originally, the layout of the stopes was in the form of an inverted triangle, but later, vertical longwall faces were kept on a straight line over many levels as illustrated in Figure 12.

Other innovative features were to start mining where two veins intersected and to mine only one vein leaving no pillars. Mining of the second vein was done later in a stress-relaxed environment. Where a major fault intersected the veins, mining started against the fault under the lowest stress conditions and retreated away from the fault.

Development drifts were arched to reduce strain bursting. Near active stoping areas circular steel sets with lagging and sand infilling were used. However, these sets were considerably damaged when subjected to rockbursts, as illustrated in Figure 13.

Some novel support techniques were used in drifts opposite highly

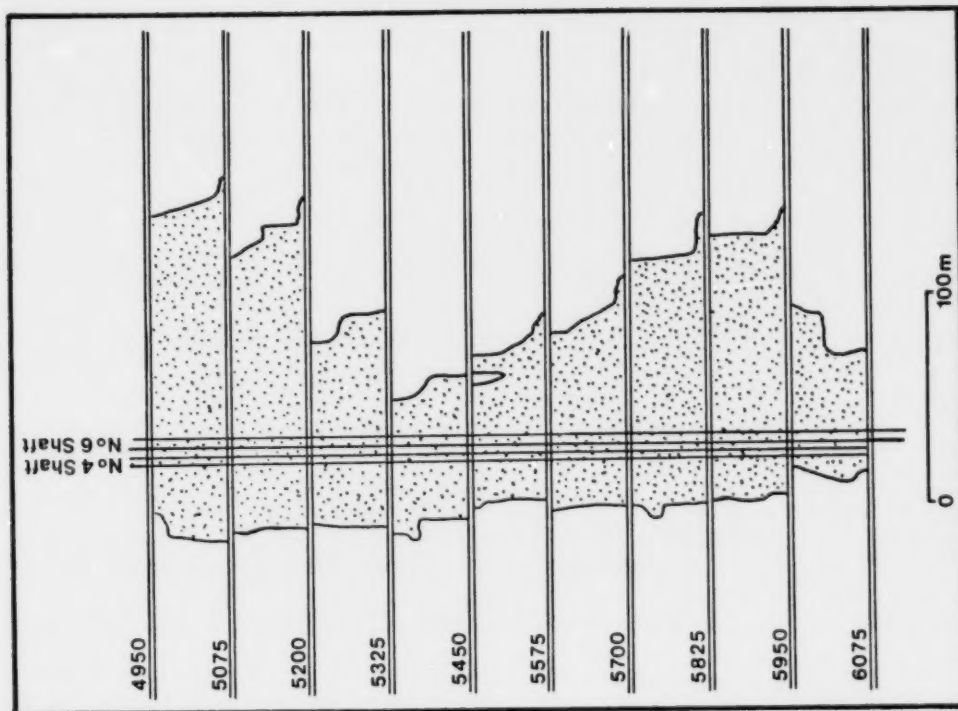


Fig. 12 - Mining layout at Lake Shore Mine showing stope alignment (after Robson, 1957).



Fig. 13 - Damage to circular steel sets caused by a rockburst (courtesy of Lac Minerals Ltd.).

stressed pillars. To protect the back two steel cables were run down the complete length of the drift, anchored at 5 m intervals with 2 m long rock bolts. Round lagging was placed between the cable and the back to form a wooden mat. Sometimes this technique was also used on the walls. In many respects, this type of support was the fore-runner of modern day lacing. The wooden mat/steel cable formed a yielding membrane which cushioned the impact of a rockburst.

ROCKBURSTS AT THE WRIGHT-HARGREAVES MINE

The Wright-Hargreaves Mine is adjacent to the Lake Shore Mine at Kirkland Land and mined the same two veins, North and South about 150 m apart. Figure 14 shows a longitudinal section of the middle part of the mine, plus a cross-section through the shafts. The geological structure is much more complex. In addition to the cross-faults, a series of strike-faults have displaced the veins and produced a number of separate blocks (i.e., in comparison to the continuity of the veins at Lake Shore shown in Figure 2).

Rockbursts first occurred at the Wright-Hargreaves Mine in 1932, and by the late 1930's had become a major problem. Over the life of the mine 227 rockbursts were recorded resulting in 52 injuries including 7 fatalities. It was observed that 83% of the rockbursts were triggered by blasting and 86% of them occurred in the North vein.

All major service openings including shafts, ventilation raises and ore passes were located between the two major veins, in the same cross-section near the centre of the property. These were already in place by 1938 when bursting became a major problem.

Mining methods were the same as at Lake Shore, mainly cut-and-fill with a rill configuration. However, the blocky nature of the orebody resulted in leaving numerous remnant pillars, as evident in the longitudinal section, Figure 14. Where the veins were more than 20 m from the shafts they were

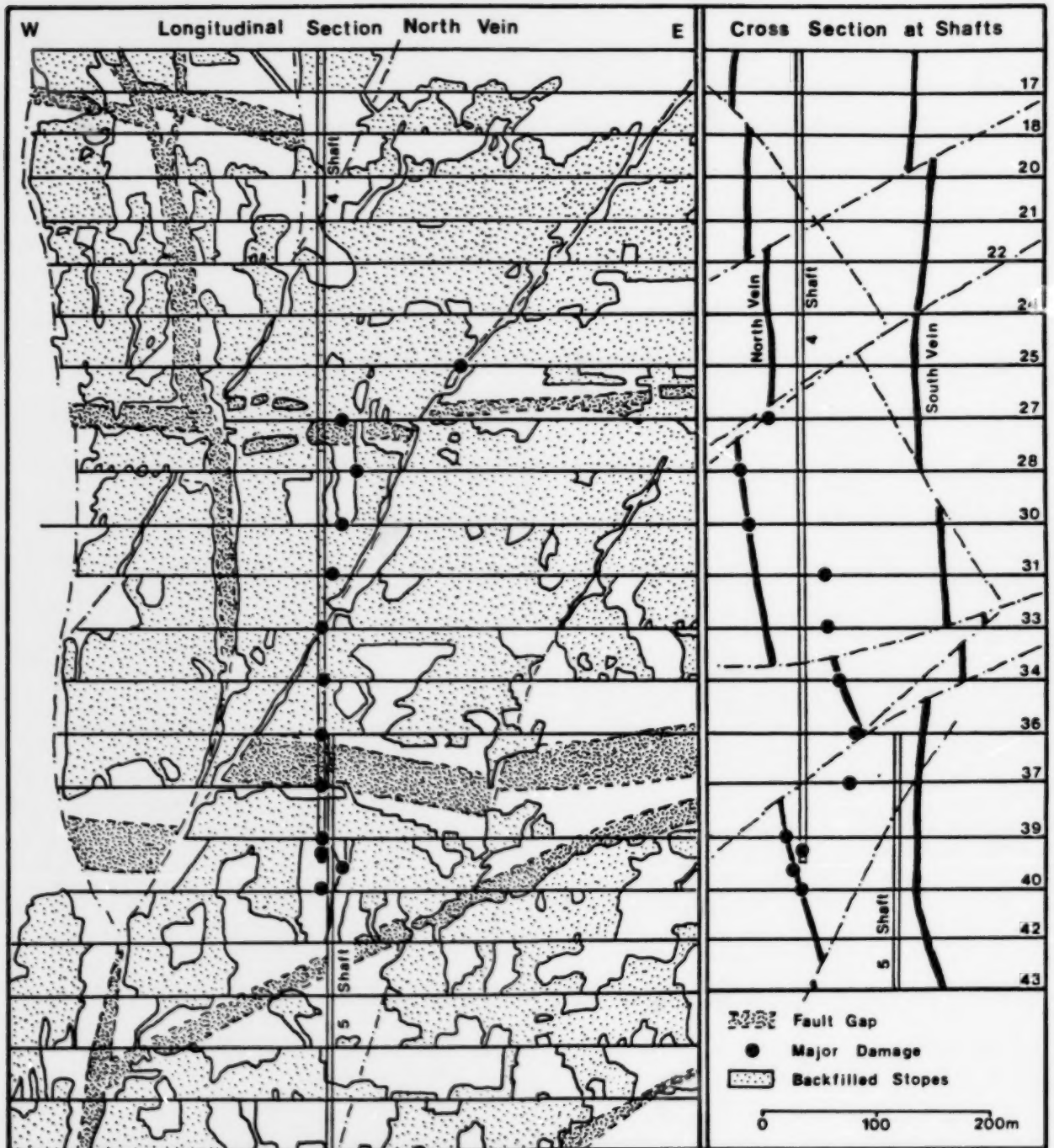


Fig. 14 - Mining layout at the Wright-Hargreaves Mine at the time of a major rockburst (after Buckle, 1964).

mined, otherwise a shaft pillar was left.

By 1964, only a few months of ore reserves remained and limited mining was taking place in the pillar opposite the No. 4 shaft on the 36 and 40 levels. At 9:28 pm on August 14, 1964, a large rockburst occurred without warning, somewhere near the operating stope on the 40 level, and resulted in two fatalities. At 11:52 pm on the same night a more violent rockburst occurred. From seismograph records the estimated magnitude was at least 4.0, which represents the largest rockburst recorded in Canada. Seismic activity gradually diminished over the next two days.

Inspection of the workings found significant damage to the No. 4 shaft and the shaft pillar. Between the 27 and 40 levels all the cross-cuts connecting the shaft to the North vein were completely blocked as indicated in Figure 14. Below the 39 level the No. 4 shaft was completely full of broken rock and above the shaft timbers were severely damaged. The lateral extent of the damage was unknown due to lack of access. The extent of the damage and limited ore reserves resulted in the immediate closure of the mine.

From these observations on the amount and extent of the damage it appears that the shaft pillar burst. However, it is possible that slippage occurred along the major strike faults, intersecting the veins in this area.

RECENT SEISMIC ACTIVITY AND RESEARCH

There has been a significant increase in seismic activity in Ontario mines in the 1980's. Fourteen mines in the Red Lake, Elliot Lake, Sudbury and Kirkland Lake mining districts have experienced seismic events including rockbursts. The breakdown of the number of seismic events, of magnitude 2.0 and greater, by mining district and individual mines, for the years 1984 to 1987 is given in Table 1. It will be noticed that these numbers do not correspond to the reported rockbursts shown in Figure 1. This is because some

Table 1 - Seismic events of magnitude 2.0 and greater
in Ontario mines 1984-1987.

Mining District	1984	1985	1986	1987	Totals
Red Lake	18	3	6	0	27
Elliot Lake	46	74	13	8	141
Sudbury	15	20	35	31	101
Kirkland Lake	5	2	3	2	12
Totals	84	99	57	41	281

<u>Red Lake</u>	<u>Number</u>	<u>Largest Magnitude</u>
Campbell Mine	23	3.3
Dickenson Mine	4	2.1
<u>Elliot Lake</u>		
Denison Mine	10	2.8
Quirke Mine	131	3.4
<u>Sudbury</u>		
Falconbridge Mine	7	3.5
Fraser Mine	1	2.5
Lockerby Mine	2	2.6
Strathcona Mine	28	3.2
Copper Cliff North Mine	16	2.9
Creighton Mine	43	4.0
Levack Mine	3	2.6
Stobie Mine	1	2.4
<u>Kirkland Lake</u>		
Kerr Addison Mine	1	3.3
Macassa Mine	11	3.1

of these seismic events caused no damage, while others occurred in abandoned areas and could not be confirmed as rockbursts.

Quirke Mine at Elliot Lake dominates the statistics and accounts for almost 50% of these events. Other mines with significant seismic activity are the Campbell Mine at Red Lake, the Strathcona, Creighton and Copper Cliff North mines in Sudbury, and to a lesser extent the Denison Mine at Elliot Lake and the Macassa Mine at Kirkland Lake. Detailed case histories of the seismicity at these mines are to be written separately.

A variety of ore deposits and mining methods are used in these mines. At Red Lake and Kirkland Lake, narrow steeply-dipping vein deposits are extracted by shrinkage and longitudinal cut-and-fill methods. At Elliot Lake gently-dipping reef deposits are mined by variations of room-and-pillar methods. At Sudbury, massive sulphide deposits are extracted by cut-and-fill and blasthole methods.

The predominant mechanism of rockbursts at Red Lake, Kirkland Lake and Elliot Lake is pillar bursts within the orebodies. In the Sudbury mines some strain and pillar bursts do occur in the orebodies, but the very large seismic events tend to occur in the wall rocks and are thought to be a fault-slip mechanism.

One peculiarity in the recent increase in seismic activity is that it occurred in the same time period in mines across the province. These mines are in different geological settings with different life spans, depth and areal extent. Similarly, in the 1930's rockbursts started at the Kirkland Lake and Sudbury mines at the same time. The Precambrian Shield in Northern Ontario is considered to be a stable area with a low level of natural earthquake activity. Consequently, it is difficult to explain these coincidences.

Another feature of the recent seismic activity has been the multiple

nature of the occurrences. Previously, rockbursts had occurred as isolated events followed by some microseismic activity. The exception was the rockburst incidents at the Wright-Hargreaves Mine in 1964, as described previously. In the 1980's multiple rockbursts have occurred at the Campbell Mine (1983), the Falconbridge Mine (1984), the Creighton Mine (1984), and twice at the Quirke Mine (1982, 1984/85). The duration of these multiple rockbursts has ranged from two hours at the Creighton Mine to five months at the Quirke Mine.

In response to this increased seismic and rockburst activity the Canada/Ontario/Industry rockburst project was initiated in 1985 (Udd, 1984). It is a joint government-industry project organized on a tripartite footing with participation of the Canada Centre for Mineral and Energy Technology (CANMET), the Ontario Ministries of Labour and Mines, and the Ontario mining industry represented by Denison Mines Ltd., Falconbridge Ltd., INCO Ltd., Lac Minerals Ltd., Placer Dome Ltd., and Rio Algom Ltd.

One of the first initiatives of this project was to improve the regional monitoring of seismic events by installing seismograph stations in Sudbury, Elliot Lake, Red Lake and Kirkland Lake. The system in Sudbury is the most sophisticated with three stations installed around the rim of the Sudbury Basin. Magnitudes of down to 1.0 can now be determined for seismic events in the Sudbury and Elliot Lake Mines.

For the first time since the early 1940's, basic research is being done on the causes and mechanisms of rockbursts. The objectives are to develop methods which diminish the number and severity of rockbursts and techniques to control either the timing or damage, rather than the prediction of rockbursts. Towards this end, macroseismic systems are being installed around the most seismically active mines. These systems capture the complete seismic waveform from which the first motion, spectral frequency, peak particle velocity and

seismic energy can be obtained. These parameters are related to the mechanism and size of the source as well as likely damage from a rockburst.

As mentioned previously the geophysical research and seismic monitoring in the early 1940's floundered due to the primitive electronics, saturation with data and its manual analysis and interpretation. All this has changed by the 1980's with multi-channel microseismic systems commercially available which give location of seismic events within a few seconds, usually at the engineering office on surface. In Ontario, the first microseismic system was installed at the Creighton Mine in 1980, followed by the Falconbridge Mine in 1981, and Quirke Mine in 1982. By 1988, fourteen microseismic systems, with up to 64 geophones per system, have been installed in Ontario mines.

The mining companies have made enormous progress in the analysis and display of the seismic data. It is not uncommon for the seismic events to be automatically plotted on mine plans and sections on a daily basis.

ACKNOWLEDGEMENTS

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